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TELEVISION TESTS WITH THE SYNCOM II SYNCHRONOUS COMMUNICATIONS SATELLITE

by Varice F. Henry and Michael E. McDonald

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SUMMARY

The results of a series of experimental tests employing a reduced video bandwidth of 2.5 Mc with the restricted radio frequency bandwidth of 5 Mc in the Syncom II satellite are described. These tests were designed to explore the feasibility of television transmissions for demonstration purposes only because the original system design parameters were based on a few channels of voice transmissions. Emphasis is placed on the microwave parameters of the transmitting and receiving ground terminals, located at Ft. Dix, New Jersey and Andover, Maine respectively. Quantitative and qualitative evaluations of the results are presented, as well as recorded samples of the received video signals which represent the first successful transmissions of standard monochrome television signals in real-time through a synchronous satellite.

CONTENTS

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INTRODUCTION

The Syncom II communications spacecraft (1963 31A) launched on July 26, 1963, was designed primarily as an active repeater satellite capable of simultaneous two-way transmission of several telephony channels. Following its placement in a 22,300-mile synchronous orbit, early in August 1963 narrowband communications experiments were successfully conducted.

In an extension of the planned experimentation, tests were conducted to evaluate the Syncom II system capability for handling a reduced bandwidth television signal. A series of tests utilizing the Syncom II spacecraft was initiated in August 1963 and, in September 1963, culminated in the first successful transmission of television through a synchronous satellite. A second series of tests was conducted in April 1964 to confirm the earlier results.

The Ft. Dix (New Jersey) terminal of the U.S. Army Satellite Agency, and the Andover (Maine) Satellite Ground Station of American Telephone and Telegraph (AT&T) were selected for transmitting and receiving sites, respectively. Details of the site modifications necessary for television transmission through the Syncom spacecraft are described under "Ground Terminals" of this paper.

Preliminary system link calculations and measurements on a spacecraft simulator indicated that because of reduced bandwidth the spacecraft-to-ground RF link should provide a marginal television picture. With a carrier-to-noise ratio of approximately 10 db at the Andover station, a video signal-to-noise ratio of approximately 25 db could be expected. The experimental results were in close agreement with these predictions, and are discussed under "Spacecraft Transmission Tests" and reviewed under "Summary of Results."

The section, "Spacecraft Characteristics," is devoted to a description of the electrical characteristics of the (Syncom) wideband transponder, and the preliminary system tests which were performed with spacecraft simulators prior to the experimental television transmissions through the satellite are discussed under "Simulated Transmission Tests."

GROUND TERMINALS

Transmission Terminal

The transmitter ground terminal, shown in Figure 1, was located at Ft. Dix, Lakehurst, New Jersey. This station was originally built for the Advent satellite system, and was later converted for use with the Syncom satellites.

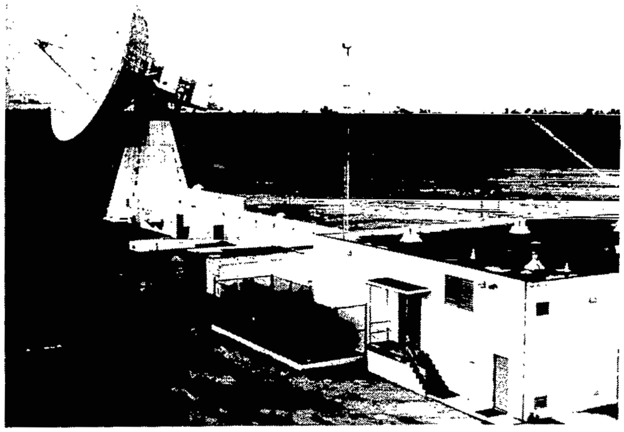


Figure 1—Ft. Dix Ground Station.

The basic antenna system consists of a 60-foot parabolic dish with a duplexed prime-focus feed for transmitting and receiving. Manual autotracking and program tracking are available.

Dual transmitters provide a choice of either 10-kw or 20-kw cw power output. The receiver front end has a parametric amplifier with a system noise temperature of approximately 200°K. The remainder of the equipment used in the television-tests circuitry is described under "Simulated Transmission Tests," a simplified block diagram is shown in Figure 2, and the transmitter characteristics for the Syncom television tests are presented in Table 1.

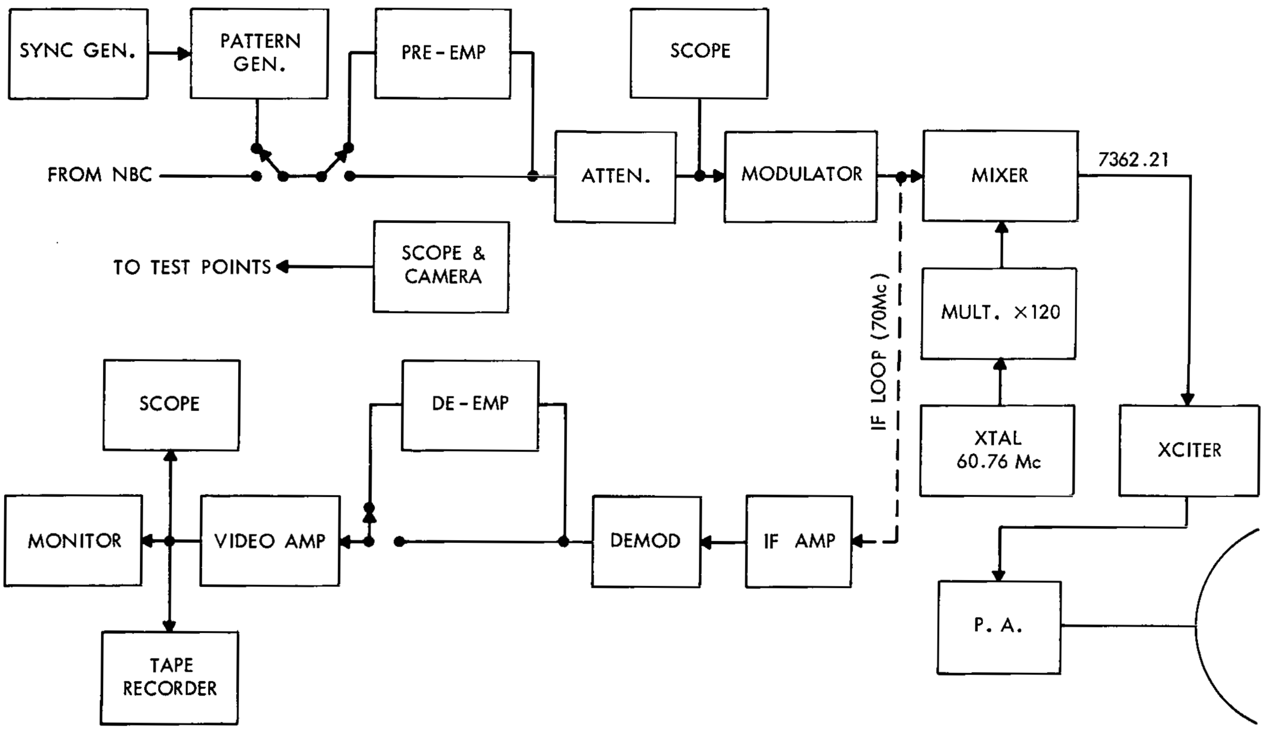


Figure 2—Ft. Dix Transmission Test Setup.

The relatively high thermal noise of 23 db for the Ft. Dix receiver made it impractical to receive television signals from the Syncom satellite primarily because the carrier-to-noise ratio of the received signal would be approximately 10 db below threshold. Therefore, the Ft. Dix receiving system was used only in the simulated transmission tests to determine the feasibility of television transmissions and the response characteristics of the Syncom communications transponder. Simulated transmission tests are described in a later section.

Table 1

Ft. Dix Transmitter Characteristics.

Power Output	10 kw
Antenna Type	60 ft Parabola
Antenna Efficiency	50%
Antenna Polarization	Circular (RH)
Frequency	7360 ± 5 Mc
Modulation	Angle (FM or PM)
IF and RF Bandwidth	14 Mc (max)
Baseband Response	10 cps to 5 Mc
Peak Frequency Deviation	8 Mc (max)

Receiving Terminal

Because of its high-gain horn antenna and low-noise receiver system, the AT&T ground station at Andover (Figure 3) was chosen for the receiver ground terminal in the Syncom television tests.

To receive wideband FM signals from the Syncom spacecraft it was necessary to make additions and modifications to the existing equipment at the Andover station including a new feed and maser preamplifier. Figure 4a is a block diagram of the equipment setup for the Syncom television tests, and the corollary receiver characteristics are presented in Table 2. The transmission characteristics of the IF and video signal and noise processing networks are illustrated in Figures 4b, 4c and 4d.

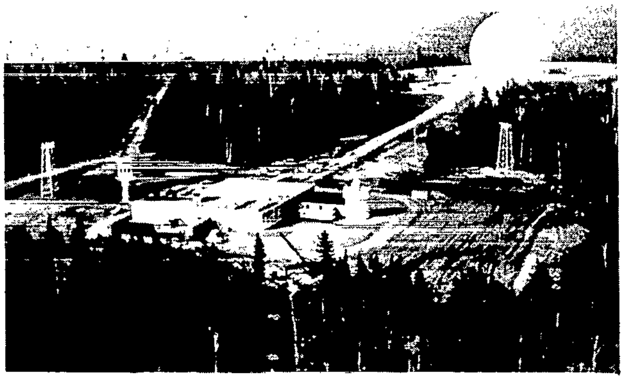


Figure 3—Andover Ground Station.

A quarter-wave probe was inserted into the apex taper section of the horn antenna to provide a receiving feed at 1815 Mc. The apex section was manually rotated to match the probe with the linear polarization of the received signal. This required periodic manual adjustments every two hours to compensate for polarization changes due to satellite motion. The probe was coupled by a low-loss coaxial cable to the maser amplifier input.

The maser, which Bell Telephone Laboratories (BTL) constructed for this experiment, was a travelling wave ruby maser centered on a frequency of 1815 Mc. The pump oscillator was a klystron at 11.9 gc with about +20 dbm output. The received signal was then converted in a balanced crystal mixer to 74 Mc, amplified, and then limited in bandwidth by interchangeable filters with bandwidths of 3 Mc and 6 Mc. The signal was coupled to both a standard frequency-modulation discriminator and a receiver demodulator utilizing frequency feedback. A detailed

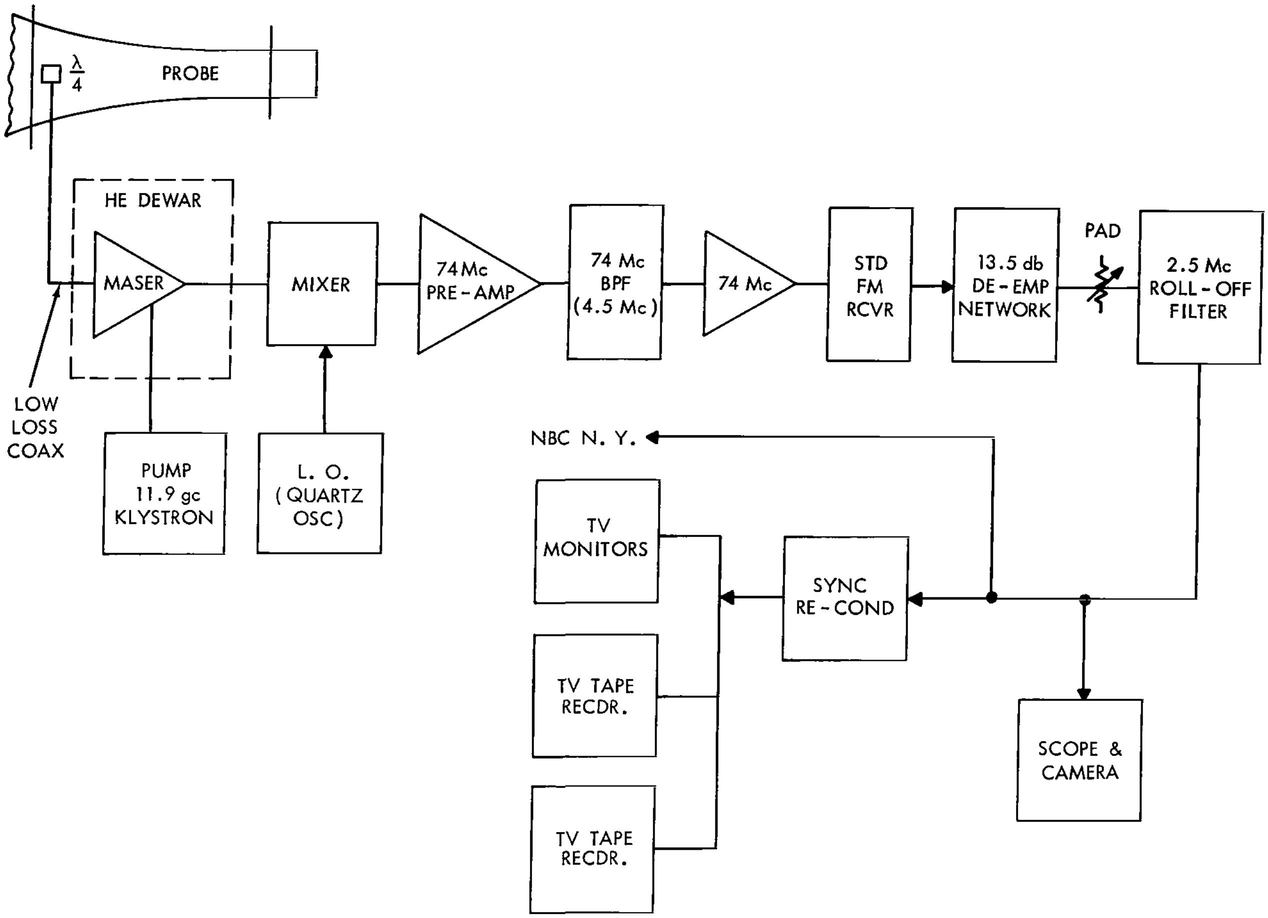


Figure 4a—Andover Receiver Circuit.

Table 2

Andover Receiver Characteristics.

System Noise Temperature	50°K (nominal)
Frequency	1815 ± 5 Mc
Antenna Type	Conical - Horn
Antenna Gain	50.5 db
Antenna Aperture	3600 sq ft
Antenna Polarization	Linear (adjustable)
Preamplifier Bandwidth	13 Mc
IF Bandwidth	3, 4.5, 6 Mc

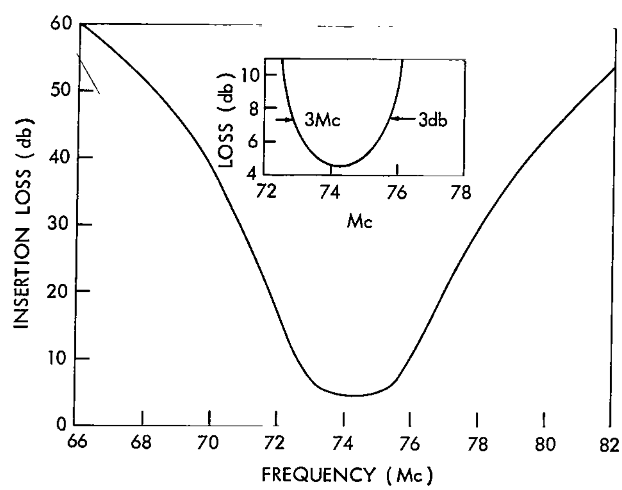


Figure 4b—Transmission Characteristic, IF Bandpass Filter.

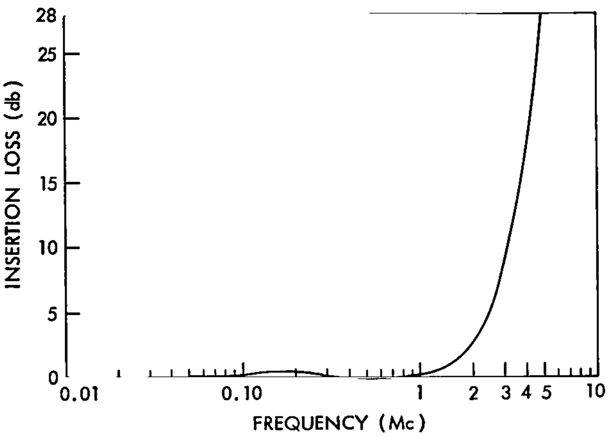


Figure 4c—Response Characteristic, Video Roll-off Filter.

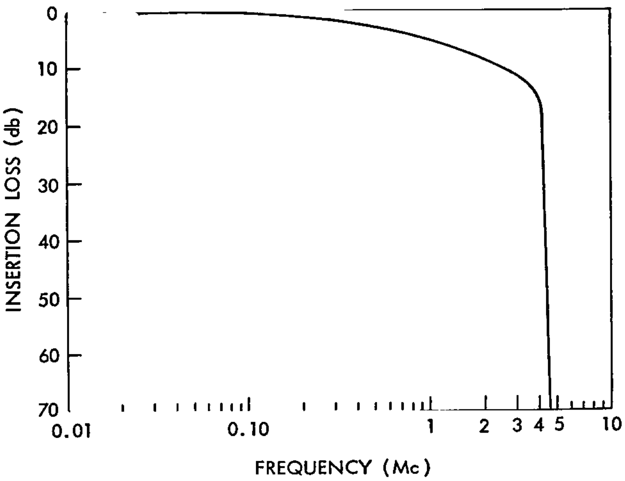


Figure 4d—Response Characteristic, Video Noise Weighting Network.

description of the basic receiver system (which was originally developed for the Telstar experiments) is presented in Reference 1. The demodulated output of both receivers provided simultaneous comparison of the demodulation techniques. De-emphasis networks were provided to complement the pre-emphasis networks in the transmitter at Ft. Dix.

Spacecraft tracking by the horn antenna was achieved by means of programmed drive tapes generated at Andover from orbital predictions supplied by Goddard Space Flight Center (GSFC). No tracking problems were encountered during the tests. As a matter of fact, no difficulty was encountered with manual tracking either; because knowledge of the satellite course, acquired from GSFC orbital predictions, provided the necessary information for tracking the satellite's position which was changing at a maximum angular rate of 4.5 degrees per hour. Table 3

Table 3

Syncom II Tracking Data For Andover Based Upon Orbital Elements.*

Year	Mo	Day	HRM (GMT)	Azimuth (deg)	Elev (deg)	Slant Range (km)	Sub-Satellite Radius N. Lat. (deg)	Sub-Satellite Radius W. Long. (deg)
1964	4	23	1802	261.37	39.23	38001.68	25.46	120.33
1964	4	23	1832	263.95	41.21	37842.00	27.96	119.96
1964	4	23	1902	265.88	43.09	37694.59	29.98	119.25
1964	4	23	1932	267.04	44.83	37560.42	31.47	118.24
1964	4	23	2002	267.36	46.37	37443.09	32.38	117.00
1964	4	23	2032	266.75	47.63	37346.95	32.68	115.65

*Drive Tape for Pass No. 0
Start Time – 18. 0. -0.

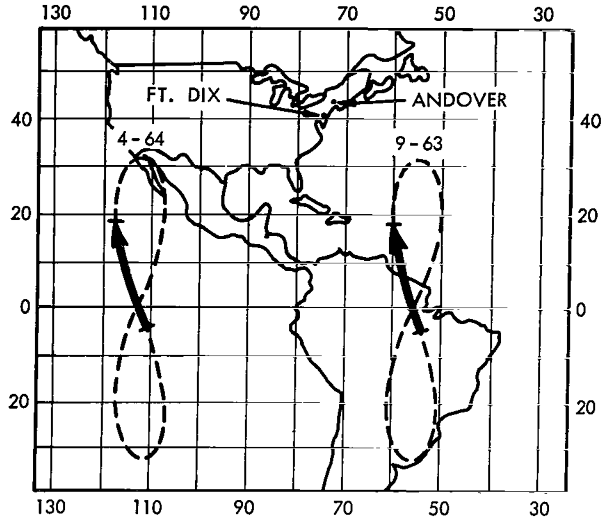


Figure 5—Sub-satellite Positions for the September 1963 and April 1964 Television Tests.

Table 4

Syncom II Tracking Data For Ft. Dix Based Upon Orbital Elements.*

Year	Mo	Day	HRM (GMT)	Azimuth (deg)	Elev (deg)	Slant Range (km)
1964	4	23	1802	263.35	43.28	37704
1964	4	23	1832	266.36	45.03	37571
1964	4	23	1902	268.68	46.73	37444
1964	4	23	1932	270.20	48.35	37326
1964	4	23	2002	270.78	49.84	37219
1964	4	23	2032	270.35	51.14	37126

*Drive Tape for Pass No. 0
Start Time – 18. 0. -0.

is a condensed tabulation of tracking data samples for Andover during the second series of TV transmission tests in April 1964. Table 4 shows the corresponding data for Ft. Dix, and Figure 5 illustrates the suborbital trajectories of the satellite for the two series of tests conducted in September 1963 and April 1964.

The range data in Tables 3 and 4 show that the total microwave propagation path between stations via the Syncom satellite was greater than 75,000 kilometers.

SPACECRAFT CHARACTERISTICS

Syncom II is a spin stabilized, synchronous, active communications satellite (Figure 6). The communications subsystem contains two frequency translation transponders: one narrowband, and one wideband. For this particular experiment the wideband transponder with an RF bandwidth of approximately 5 Mc was utilized.

Figure 7 is a block diagram of the spacecraft communications subsystem. The 7362-Mc

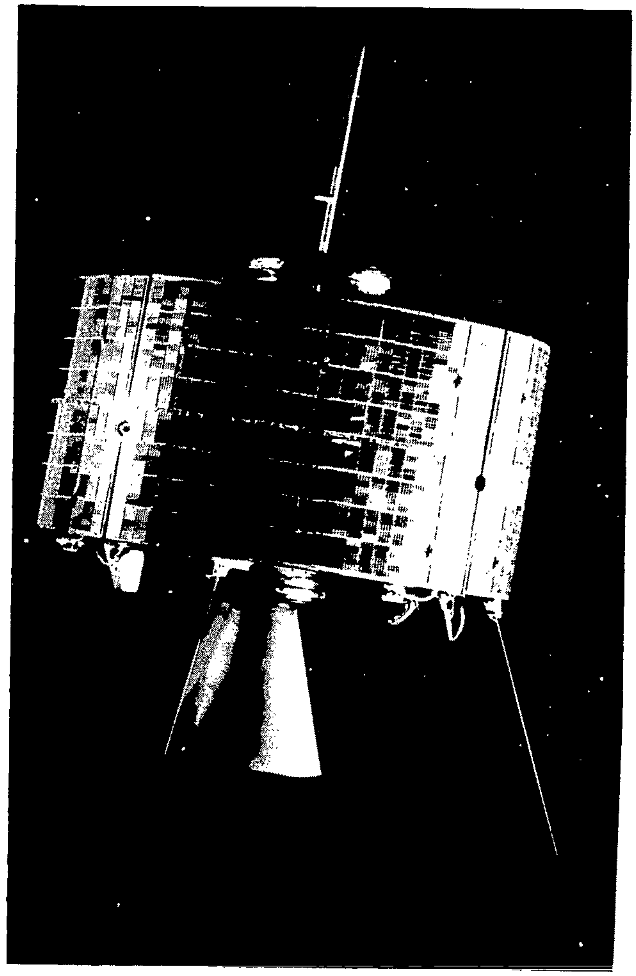


Figure 6—Syncom II Spacecraft.

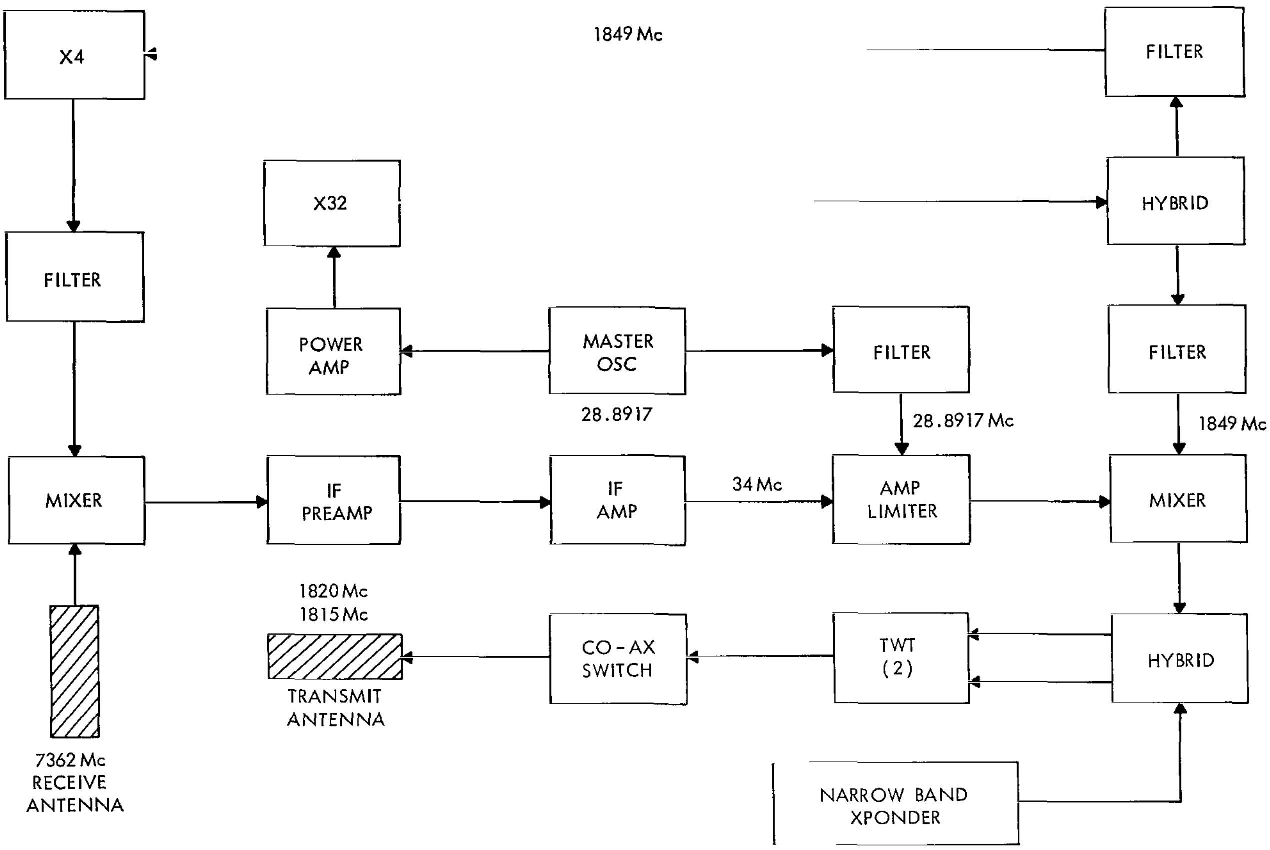


Figure 7—Syncom II Communications Subsystem.

signals received by the spacecraft slot-dipole antenna are mixed with a local oscillator frequency of 7396 Mc to obtain an intermediate frequency of 34 Mc. This local-oscillator frequency is the 256th harmonic of the master crystal oscillator which operates at 28.8917 Mc. The IF signal passes through a preamplifier with a gain of 45 db, an IF amplifier, and is then limited in a limiter amplifier. The beacon is added and the two signals are then mixed with the transmitter local oscillator frequency 1849 Mc which is the 64th harmonic of the master oscillator. The output signals are filtered and fed to an interconnecting hybrid. This hybrid couples the narrowband and wideband transponder outputs. The one milliwatt signal from the hybrid drives a travelling wave tube (TWT) having a gain of 33 db to produce a nominal output level of 2 watts. Two TWTs are provided for redundancy, either of which is selectable via remote command. Table 5 gives some of the spacecraft transponder characteristics.

SIMULATED TRANSMISSION TESTS

Prior to actual transmissions with the orbiting spacecraft, engineering tests were conducted with spacecraft simulators at the Ft. Dix site, Lakehurst, New Jersey and Bell Telephone Laboratories, Murray Hill, New Jersey.

Table 5

Syncom II Wideband Transponder Characteristics.

Transmitter

Power Amplifier	Travelling Wave Tube
Power Output	+34 dbm
Carrier Frequency	1815 Mc
Beacon Power	+20 dbm
Beacon Frequency	1820.177 Mc

Receiver

Type	Frequency Translation
Carrier Frequency	7362.582 Mc
Noise Figure	10 db
Channel Bandwidth (-3 db)	5 Mc (13 Mc)*

Antenna

Type	Collinear Slot Dipoles
Receiving Gain	2 db (excluding losses)
Receiving Polarization	Linear - Parallel
Transmitting Gain	6 db (excluding losses)
Transmitting Polarization	Linear - Orthogonal

*Syncom III only.

Figure 2 is a block diagram of the Ft. Dix send-receive test setup used to establish the feasibility and operating parameters to be used in transmission tests with the spacecraft. Television test signals, generated by the TV test generator (Telechrome 1005), were fed into a frequency modulator (RCA MM600). Frequency deviation was adjusted by means of a variable attenuator at the modulator input. The 70-Mc output of the modulator was amplified and mixed with the synthesized signal $\left(f_{c_t} - 70 \text{ Mc}\right)$ to produce a frequency modulated signal centered at 7362 Mc $\left(f_{c_t}\right)$. This frequency-modulated RF signal was amplified and applied to a high power klystron amplifier which fed the 60-foot parabolic antenna. For simulated transmission tests with a simulator mounted on a remote tower, the high power amplifier was not used because the exciter output provided sufficient power.

The deviation sensitivity of the modulator was determined by inserting a 1.666-Mc sinusoidal signal at the input to the modulator and adjusting its level while observing the 70-Mc spectrum of the modulator for zero carrier, indicating a modulation index of 2.40 (Reference 2). The corresponding frequency deviation is given by,

$$\text{modulation index} = \frac{\text{peak deviation}}{\text{modulation frequency}} .$$

At Ft. Dix the spacecraft simulator output signal was received on a 60-foot parabolic antenna. It was then fed through a parametric amplifier and a TWT amplifier to a diplexer which removed the 1820-Mc beacon signal. The diplexed 1815-Mc communications signal $\left(f_{c_r}\right.$, center frequency of the ground receiver$\left.\right)$ was mixed with 1745 Mc $\left(f_{c_r} - 70\right)$ from the synthesizer in order to yield the 70-Mc IF signal. The IF was limited, amplified, and demodulated.

Test signals were looped through the system at baseband, IF and RF frequencies to establish the component contribution to noise and frequency response. The ground system was essentially flat from zero to 4.5 Mc at baseband, and for ±5 Mc from the IF and RF center frequencies.

To determine if pre-emphasis would enhance the picture quality, filter networks supplied by BTL were inserted in the circuit. Figure 8 indicates the characteristic frequency response of the filter networks. The combined effect of the filter circuits provides a net attenuation of 13.8 db of the low frequencies in the baseband signal spectrum with cross-over occurring at 400 kc. Transmissions with and without pre-emphasis indicated that the networks did improve picture quality.

The simulator tests indicated that peak-to-peak deviations of 4.0 to 5.0 Mc would provide optimum signal-to-noise ratios. Adjustments of the receiver carrier-to-noise ratio to simulate an expected 10-db C/N at Andover, and observations of the TV monitor at Ft. Dix indicated that although the signal level was marginal, fair quality picture transmissions should be feasible. Similar tests at Bell Telephone Laboratories yielded corresponding results.

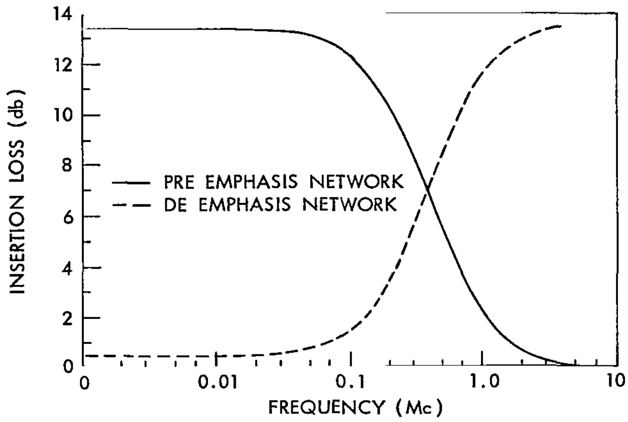


Figure 8—Syncom II Television Tests Pre-emphasis Characteristics.

SPACECRAFT TRANSMISSION TESTS

Preliminary spacecraft-simulator tests were completed first to establish which basic parameters were to be evaluated; then, on September 29, 1963, spacecraft testing was begun.

The time of the test period was selected to provide test data when the spacecraft was near the equator. This period gives data that is applicable to an equatorial synchronous orbit. Figure 5 shows the sub-satellite orbit of the spacecraft and indicates the approximate positions during the three day test period.

When the 1820-Mc spacecraft beacon was first acquired by the Andover station its level was -107.1 dbm. Then an unmodulated carrier was transmitted from the Ft. Dix site to the spacecraft. After adjustments to the polarization sensor at Andover, the measured communications carrier signal level was -106.5 dbm. Video transmissions were initiated following carrier-to-noise measurements. The first television test transmission through the Syncom satellite was a window pattern with a 5-Mc (peak-to-peak) carrier deviation. A photograph of the received signal is shown in Figure 9.

A telechrome signal generator provided the standard monochrome test signals (multiburst, window and stairstep) for the system evaluation. To provide a source of test signals with dynamic picture content, a portable video tape recorder was used.

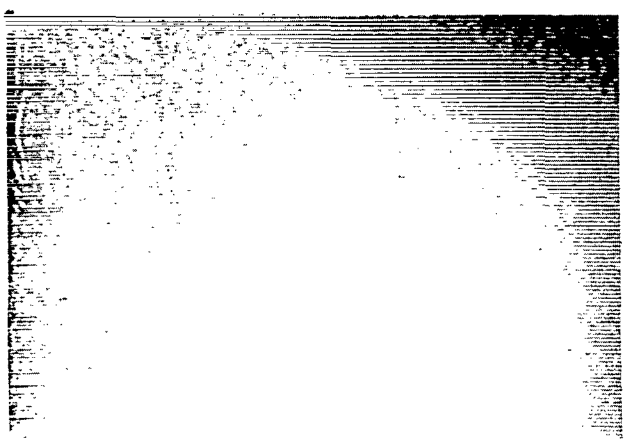


Figure 9—Photograph of First TV Signal Received Through Syncom II.

A series of evaluation tests with various deviation levels was conducted to establish an optimum set of transmission parameters. Real-time coordination between Andover and Ft. Dix operations were maintained via land lines. Details of the ground-to-satellite and satellite-to-ground link parameters are listed in Tables 6 and 7. Figures 10 through 13 present additional photographs of received video waveforms and pictures.

The satellite's northerly motion in the course of its 33° inclined orbit (with respect to the equator) enabled Andover to track at higher elevation angles (up to 47° with respect to the local horizon) and, therefore, lower noise levels were achieved during the latter part of the test period. The received carrier level improved throughout the test period and ranged from -106.5 to -104.5 dbm.

The Andover antenna gain at 1815 Mc was 50.5 db and the receiver system noise temperature, measured at zenith was 45°K. The carrier-to-noise ratios were calculated (assuming 3-Mc IF bandwidth filter in circuit) as described below.

The noise power relationship is

$$N = KTB , \tag{1}$$

where K is the Boltzmann constant (1.38×10^{-23} watt-sec/°K), T is the system noise temperature (45°K), and B is the receiver bandwidth (3×10^{6} cps). The noise power will then be

$$N = 1.86 \times 10^{-15} \text{ watts}$$

$$= -117.3 \text{ dbm} . \tag{2}$$

Table 6

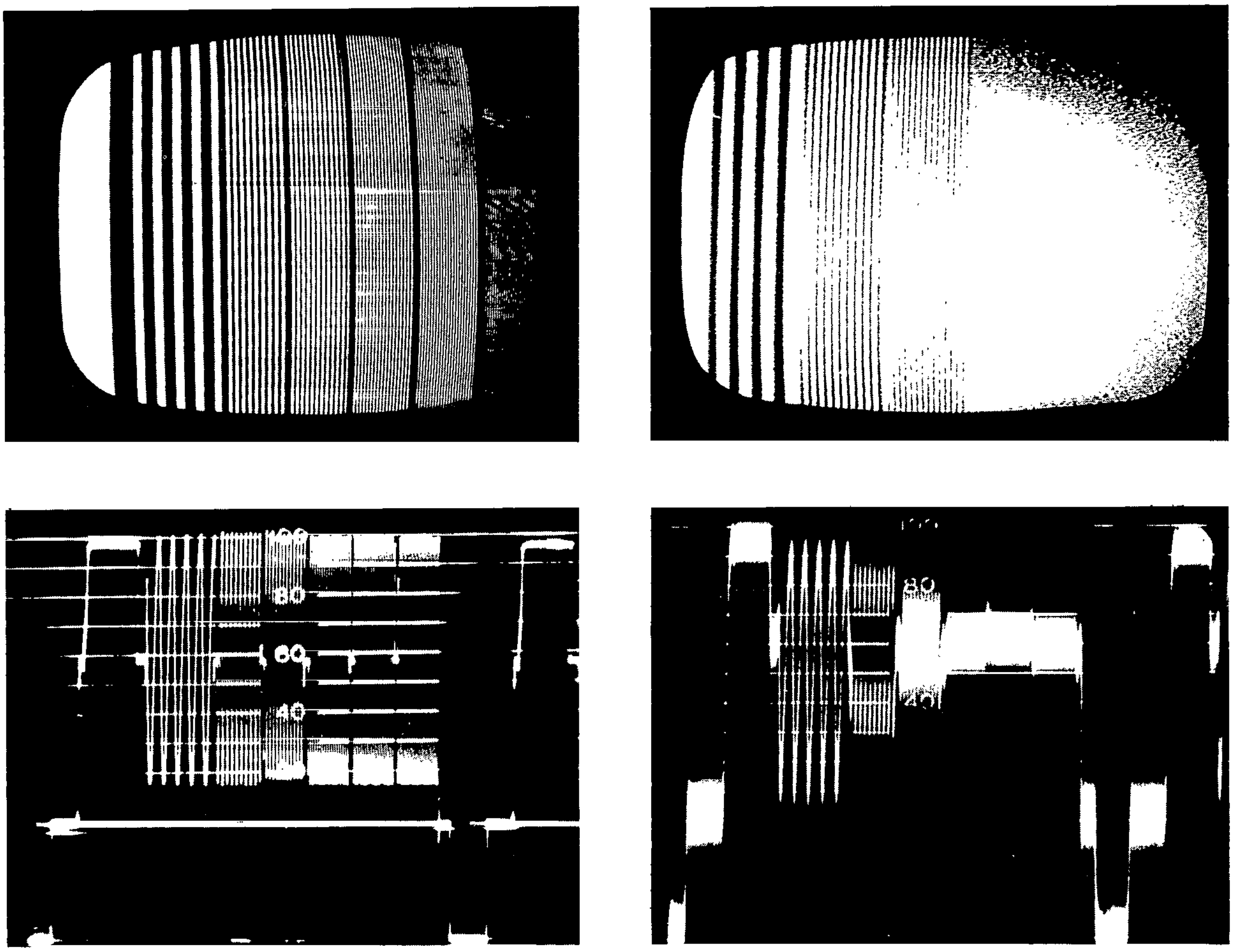
Signal Characteristics Of The Ground To Satellite Link (7360 Mc).

Ground Transmitter Power	70.0 dbm
Ground Antenna Gain (Ft. Dix)	55.0 db
Losses in Polarizer and Waveguide	-6.0 db
Free Space Loss	-201.7 db
S/C Receiver Antenna Gain	1.2 db
Losses Due to Spacecraft Look Angle	-1.0 db
S/C Losses	-0.5 db
S/C Received Signal Level	-83.0 dbm

Table 7

Signal Characteristics Of The Satellite To Ground Link (1815 Mc).

S/C Transmitter Power	34.0 dbm
S/C Losses	-3.0 db
S/C Antenna Gain	+6.0 db
Free Space Loss	-189.5 db
Losses Due to Spacecraft Look Angle	-1.0 db
Ground Antenna Gain (Andover)	50.5 db
Andover Received Signal Level	-103.0 dbm



FORT DIX TRANSMITTED PATTERNS

ANDOVER RECEIVED PATTERNS

Figure 10—Comparison of TV Signals Received and Sent Through Syncom II.

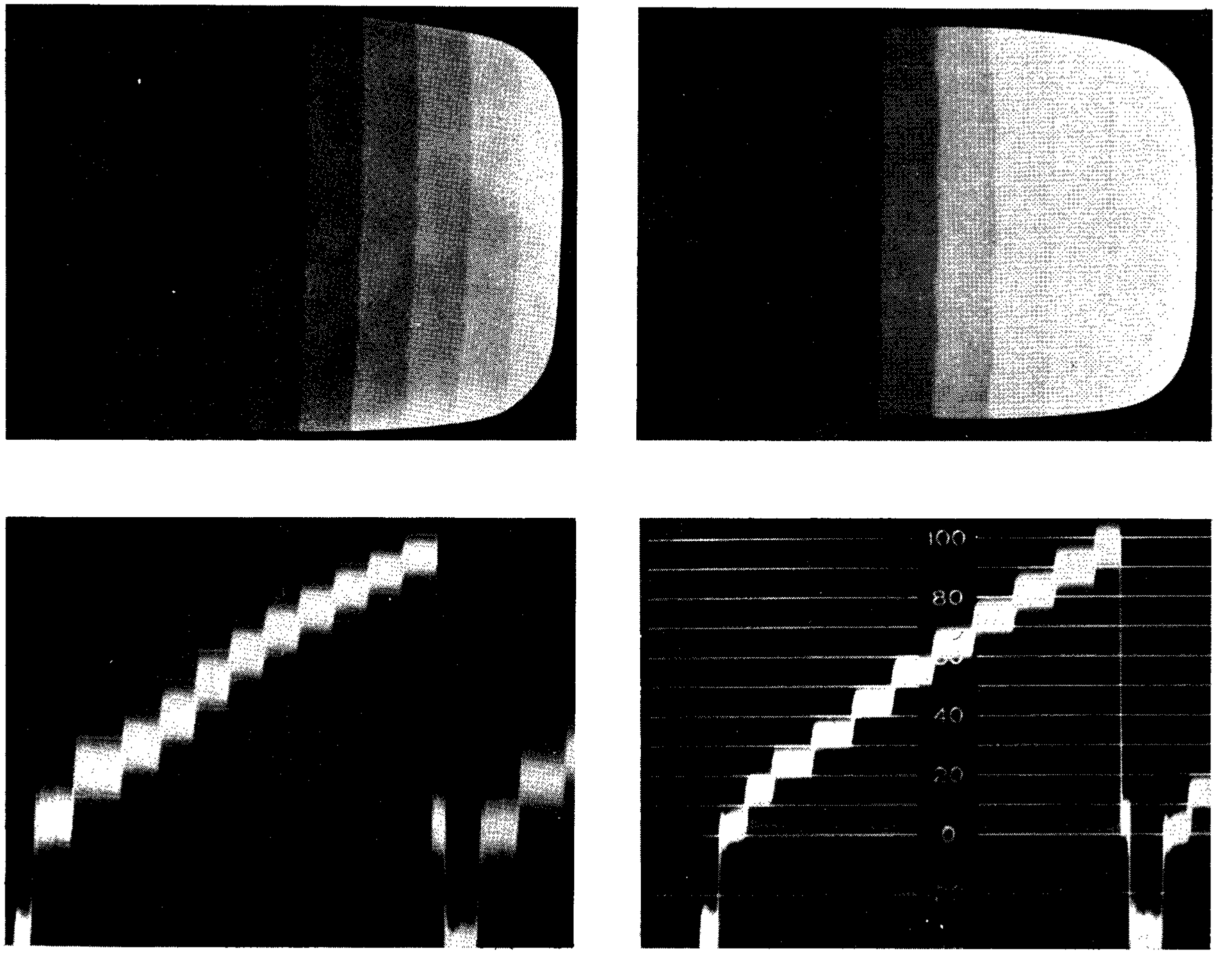
The maximum carrier-to-noise ratio (in db) will be

$$\frac{C}{N_{max}} = -104.5 + 117.3 = 12.8 \text{ db} \tag{3}$$

The signal-to-noise ratio based on peak-to-peak video to rms noise at baseband was calculated using the relation,

$$\frac{S}{N} \text{ (db)} = 10 \log \frac{C}{N} + 10 \log \frac{B}{b} + 20 \log \frac{F_{p\text{-}p} \sqrt{3}}{b} \tag{4}$$

where B is the RF bandwidth (cps), b is the maximum modulating frequency (cps), and $F_{p\text{-}p}$ is the peak-to-peak deviation of the carrier (cps).



SYNCOM RELAY

Figure 11—Comparison of TV Signals Received Through Relay and Syncom II.

Values of signal-to-noise ratios, using the above equation, indicate that peak-to-peak video to unweighted rms noise ratios between 25 and 29 db were obtained. Measurements were made of signal-to-noise ratios using a CCIR 525-line noise-weighting filter (Reference 3). The results indicate peak-to-peak video signal-to-weighted rms noise ratios of approximately 34 db were obtained. This is 16 db below Telstar and Relay performance and 20 db below recommended levels for television transmission standards, based on 525 lines and 5-Mc baseband signals (Reference 3). However, subjective studies (Reference 4) have shown that television pictures with S/N ratios of 25 db or more are "acceptable for viewing," based on 525 lines and 2.5 Mc baseband signals.

For the transmissions shown in Figure 11 the stairstep pattern was used with a 4.5-Mc peak-to-peak deviation at Ft. Dix. A 3-Mc IF bandpass filter and 3-Mc low-pass baseband filter were inserted at Andover.

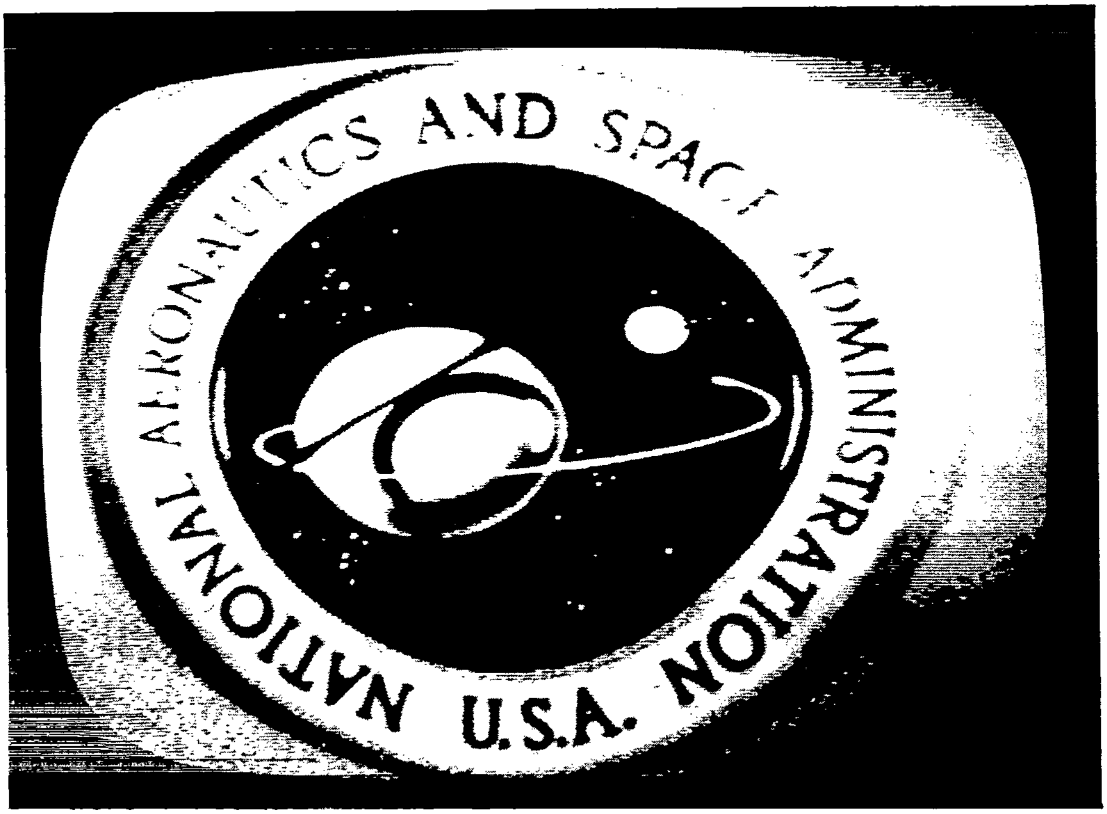


Figure 12—Photograph of NASA Seal Received Through Syncom II.

Table 8

Received Carrier vs Transmitted Power.

Ft. Dix Trans. Power (Effective Rad. Power)	Satellite Received Carrier (calculated)	Andover Received Carrier (measured)		Television Monitor Observations
dbm	dbm	dbm	C/N (db)	S/N (db)
+119	-79.7	-105.5	11.8	24.69 normal
+117	-81.7	-105.5	11.8	24.69 normal
+115	-83.7	-105.5	11.8	24.69 normal
+113	-85.7	-105.7	11.6	24.49 normal
+111	-87.7	-106.3	11.0	23.89 slight increase in noise
+109	-89.7	-108.7	< 10	20.49 large increase in noise
+107	-91.7	< -110	No Data	picture lost in noise

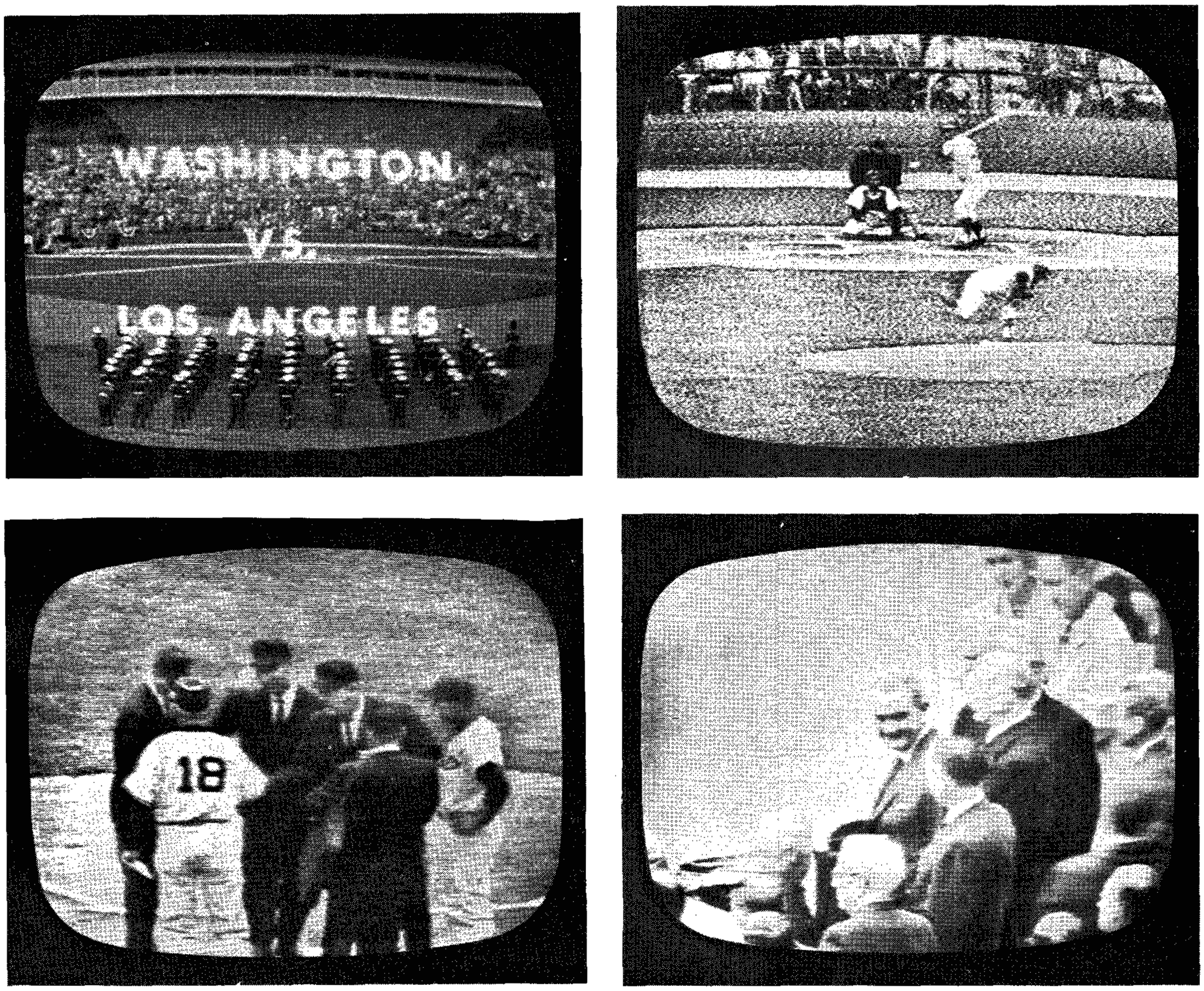


Figure 13—Photographs of TV Program Material Received Through Syncom II.

The effect of reduced transmitter power on the ground-to-spacecraft link was investigated by reducing the 10-kw output power at Ft. Dix in 2-db steps. The received carrier level at Andover was recorded, and visual observations of the monitor was made. The results are presented in Table 8 and Figure 14.

Due to spacecraft operating requirements at the time of these tests, corollary telemetry data on spacecraft agc and TWT output power were not obtained for analysis. However, as a matter of interest, curves of the effective radiated power measured on the Syncom III satellite as a function of received carrier level at the satellite are shown in Figure 15.

SUMMARY OF RESULTS

In summarizing the results of the television transmission tests with Syncom II the following items are noted.

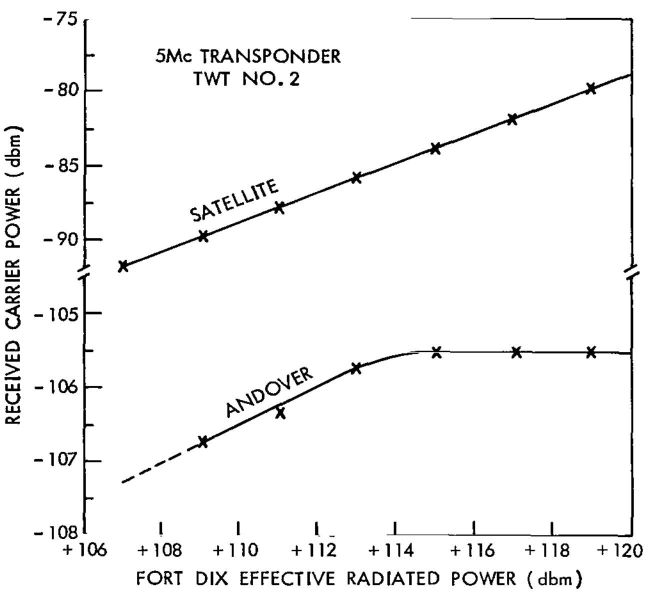


Figure 14—Syncom II TV Transmission Characteristics: Received Carrier vs Transmitted Power.

1. General feasibility of standard monochrome television transmissions using the Syncom II spacecraft was confirmed. While the quality of the received video could not be classed as "high" it did offer pictures of an "acceptable" level (Reference 4).
2. The video signal-to-weighted rms noise ratio was approximately 34 db with the Syncom II spacecraft. This could be improved in future spacecrafts by expanding the RF bandwidth and increasing the deviations. Under optimum conditions, an increase of nearly 6-db in signal-to-noise ratio could be achieved using Syncom III as illustrated in Figure 16.
3. The optimum frequency deviation of the RF carrier by the pre-emphasized video was 4.5-Mc peak-to-peak for typical program material.
4. The upper limit of video frequency response is 2.5 Mc.

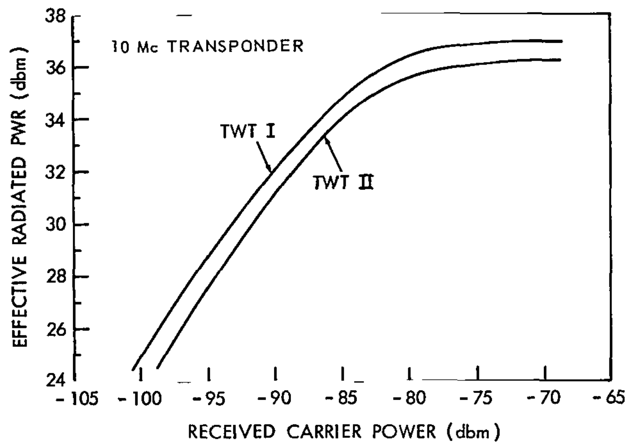


Figure 15—Syncom III Effective Radiated Power vs Received Carrier Power.

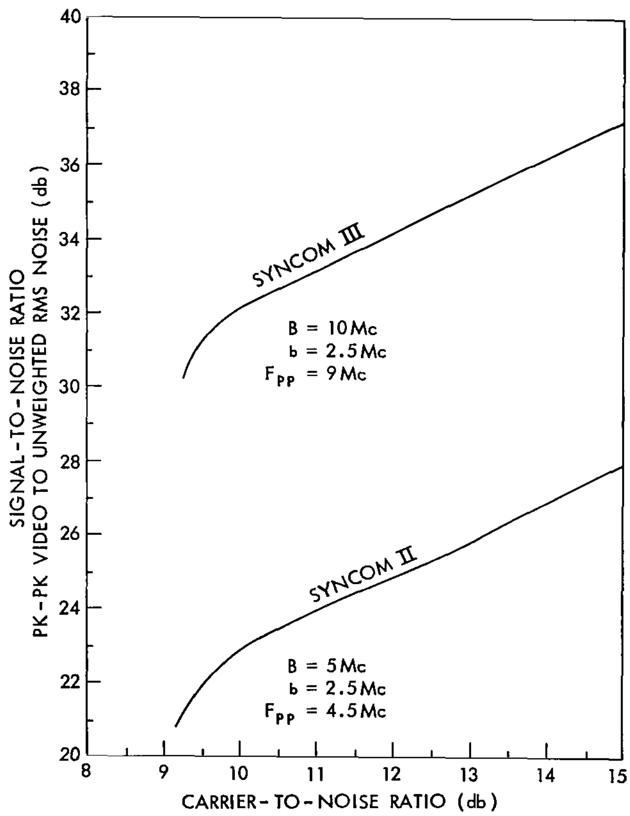


Figure 16—Syncom II and III Signal-to-Noise vs Carrier-to-Noise Ratio.

5. Video pre-emphasis of approximately 14 db is required.

6. IF bandwidth limiting to approximately 4.5 Mc in the receiver is required to optimize the signal-to-noise ratio.

7. The minimum acceptable received carrier level at the spacecraft is -87 dbm. (This corresponds to a ground transmitter output power of 2.5 kilowatts for a parabolic antenna 60 feet in diameter.)

8. No attempt was made during these tests to provide audio information with the video signal. The bandwidth limitation of the Syncom satellite imposes restrictions in the use of subcarrier techniques, but other methods such as "inter-leaving" audio information into the composite video signal should be feasible (Reference 5).

ACKNOWLEDGMENTS

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